THE CHANGING PATTERN OF REOPERATIVE CORONARY SURGERY: TRENDS IN 1230 CONSECUTIVE REOPERATIONS

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Objective: We noted an increasing risk profile of patients undergoing reoperative coronary surgery. We evaluated the risk compared with primary procedures, our results over a 16-year span, and the predictors of hospital outcomes after redo surgery.

Methods: We analyzed 20,614 patients undergoing isolated coronary surgery at our institution from 1982 to 1997. Of these, 1230 (6.0%) were undergoing reoperation. Independent predictors of outcomes were identified by multivariable regression.

Results: The prevalence of reoperation peaked in 1994 at 8.2%. Patients undergoing reoperation were more likely to be male, to have left ventricular dysfunction and worse symptoms, and to require an urgent operation than patients undergoing a primary operation ($P < .0001$). Perioperative myocardial infarctions (3.7% vs 7.4%), low-output syndrome (9.0% vs 24.0%), and death (2.4% vs 6.8%) were more common in patients undergoing reoperation (all $P < .0001$). Over the years, the risk profile of patients undergoing reoperation increased. Age, left ventricular dysfunction, severity of symptoms, extent of coronary artery disease, left main stenosis, and requirement for urgent or emergency operations increased with time ($P < .05$). However, mortality, myocardial infarction, and low-output syndrome have remained constant. The independent predictors of mortality after reoperative surgery were increased age, greater Canadian Cardiovascular Society symptom class, earlier year of operation, and greater left ventricular dysfunction. After 1990, analysis of an expanded data set also identified peripheral vascular disease and failure to use retrograde cardioplegia as predictors of mortality.

Conclusions: Improving results of reoperative surgery have been offset by an increasing patient risk profile. Meticulous operative technique and retrograde cardioplegia may permit good results in these high-risk patients. (J Thorac Cardiovasc Surg 2000;120:156-63)

Hospital morbidity and mortality during coronary bypass operations has decreased substantially during the past 2 decades. The overall mortality of coronary bypass surgery at our institution fell from 4.0% in 1982 to 2.2% in 1997. However, patients undergoing reoperative coronary surgery still face markedly elevated perioperative morbidity and mortality despite progressive advances in perioperative care and myocardial protection. We have noted a gradual rise in the prevalence of patients referred for reoperative coronary surgery over the past decade, but this prevalence has reached a plateau. The risk profile of these patients has,

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however, continued to increase. We therefore attempted to quantify the changes in the risk profile of patients requiring reoperation, to evaluate our outcomes, and to identify the independent predictors of hospital mortality and morbidity in these patients to permit more accurate risk stratification and to direct further efforts to improve outcomes.

Methods

Data source. Demographic, anatomic, intraoperative, and in-hospital outcome data were collected prospectively and entered into a computerized database on all patients undergoing cardiac operations at our institution (The Toronto Hospital, formerly the Toronto General and Toronto Western Hospitals). From this database, the records of all patients undergoing reoperative coronary artery bypass grafting between January 1, 1982, and December 31, 1997, were retrieved for analysis. Patients who underwent concomitant valve operations were excluded, as were those who were undergoing coronary operations after previous valve operations.

Core fields collected in our database since its inception in 1982 included age, sex, left ventricular (LV) grade (based on LV ejection fraction [LVEF]: grade 1, LVEF >60%; grade 2, LVEF 40%-60%; grade 3, LVEF 20%-39%; grade 4, LVEF <20%), previous coronary artery bypass operation, urgency of operation (elective; semiurgent, indicating an operation during the same admission as cardiac catheterization or a cardiac event; or emergency, indicating an operation within 12 hours of cardiac catheterization or a cardiac event), number of coronary arteries with significant stenoses, left main stenosis of greater than 50%, severity of angina, and Canadian Cardiovascular Society (CCS) symptom class. LVEF was determined semiquantitatively by contrast ventriculography. Echocardiography and nuclear ventriculography were carried out in a minority of patients, and when these additional data were available, the greatest value for LVEF obtained was used for subsequent analysis.

Starting in 1990, as we investigated alternative techniques of cardioplegia, data collection included details of cardioplegia temperature (warm [36°C-37°C], tepid [29°C-30°C], or cold) and continuity (intermittent or continuous), as well as direction of administration (antegrade, retrograde, or both). Since 1990, we have also recorded in the database the presence of particular comorbid conditions, including peripheral vascular disease, renal failure, chronic obstructive lung disease, and others. Details of this database, as well as the criteria by which postoperative low-output syndrome was defined, have been published elsewhere.[1]

Analysis. Data were collected and managed in dBase IV data sets and analyzed with SAS and BMDP/DYN LR statistical analysis software (SAS Institute, Inc, Cary, NC; BMDP Software, Los Angeles, Calif). Univariate analysis of categoric data was carried out with the χ^2 or Fisher exact tests. Univariate analysis of normally distributed continuous variables was carried out with the Student *t* test. Univariate analysis of nonnormally distributed continuous variables, such as length-of-stay parameters, was carried out with a Wilcoxon rank sum test.

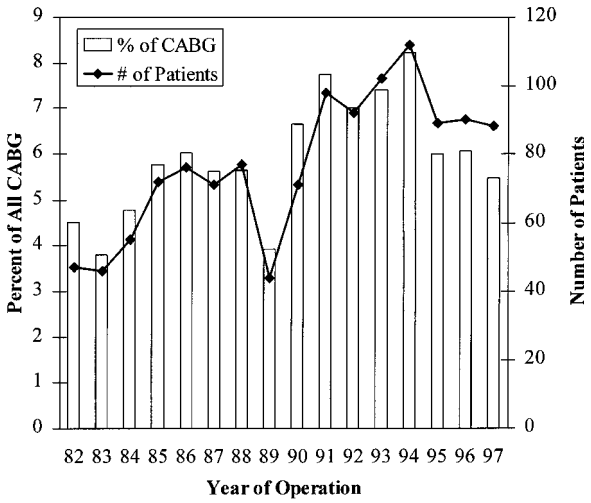

Fig 1. Relative and absolute prevalence of reoperative surgery in 20,614 patients undergoing coronary bypass operations from 1982 to 1997. Both the relative and the absolute prevalence of reoperative coronary surgery peaked in the early 1990s but have since reached a plateau. *CABG*, Coronary artery bypass grafting.

Variables that had a univariate *P* value of less than .25 or those of known biologic importance but failing to meet the critical α level were submitted for consideration to logistic regression analysis by stepwise selection. Multivariable logistic regression methods were used to calculate risk-adjusted mortality and calculate factor-adjusted odds ratios. Model discrimination was evaluated by the area under the receiver-operator-characteristic (ROC) curve, and calibration was assessed with the Hosmer-Lemeshow goodness-of-fit statistic. For goodness of fit, the null hypothesis is that the model fits the data. Therefore, a nonsignificant *P* value is desired because a *P* value of less than .05 would indicate a poor fit between predicted and observed results.

Evaluation of incremental risks caused by reoperation. We compared the risk profiles, intraoperative details, and hospital outcomes of patients undergoing primary versus reoperative coronary surgery by using χ^2 analysis, the Fisher exact test, or the Student *t* test as appropriate to assess the prevalence of risk factors for hospital outcomes and relate these differences to observed mortality and morbidity in these 2 patient populations.

Evaluation of temporal trends. Rather than constructing a complex model to assess the temporal trends in prevalence, risk profiles, and outcomes, we used a simpler approach based on risk stratification and contingency tables. To examine the effect of time on patient risk profiles and outcomes, we divided patients into 3 groups on the basis of the year of

Table I. *Primary versus reoperative coronary bypass surgery*

	Primary operation	*Reoperation*	P *value*
Demographics			
No. of patients	19,384	1230	
Male sex	79.7%	86.3%	<.0001
Age (y)	60 ± 10	61 ± 9	.02
LVEF			
>40%	77.1%	66.6%	<.0001
20%-40%	19.6%	29.2%	
<20%	3.3%	4.2%	
CCS class			
I	2.6%	0.6%	<.0001
II	16.9%	5.8%	
III	38.8%	39.9%	
IV	41.7%	53.7%	
No. of diseased vessels			
1	5.5%	5.3%	.6
2	22.1%	20.9%	
3	72.4%	73.8%	
Left main stenosis	16.5%	15.5%	.4
Urgency			
Elective	67.8%	62.6%	<.0001
Urgent	17.6%	15.5%	
Emergency	14.6%	21.9%	
Intraoperative data			
No. of grafts			
1	2.4%	7.7%	<.0001
2	11.9%	23.0%	
3	35.4%	39.1%	
4	39.6%	25.3%	
5	10.2%	4.5%	
6	0.5%	0.2%	
7	0.02%	0.08%	
LITA use			
1982-1997	68.2%	60.2%	<.0001
1992-1997	88.9%	64.9%	<.0001
Duration of CPB (min)	87 ± 30	102 ± 37	<.0001
Duration of XCL (min)	57 ± 20	62 ± 24	<.0001
Systemic hypothermia			
36°C-37°C	5.3%	3.3%	<.0001
30°C-35°C	48.5%	56.3%	
25°C-29°C	46.1%	40.2%	
<25°C	0.1%	0.2%	

	Primary operation	*Reoperation*	P *value*
Intraoperative data—cont'd			
Myocardial protection			
Coronary perfusion	0.2%	0.5%	.04
Warm blood cardioplegia	2.8%	2.0%	
Tepid blood cardioplegia	5.8%	4.7%	
Cold blood cardioplegia	91.2%	92.8%	
Outcomes			
Mortality	2.4%	6.8%	<.0001
Myocardial infarction	3.7%	7.4%	<.0001
Low-output syndrome	9.0%	24.0%	<.0001
IABP			
Preoperative in CCU	3.2%	4.6%	<.0001
Preoperative in OR	1.2%	3.6%	
Postoperative in OR	3.6%	15.1%	
Postoperative in ICU	0.8%	1.0%	
Stroke	1.7%	2.4%	.08
Reopening			
Bleeding	2.2%	2.9%	<.0001
Tamponade	0.3%	0.2%	
Shock-arrest	0.5%	1.4%	
Infection	0.5%	0.6%	
Dehiscence	0.2%	0.1%	
Redo surgery	0.2%	0.4%	
Other	0.1%	0.4%	
Sternal infection	2.2%	2.9%	.1
Duration of ventilation, d (median [25th-75th percentile])			
1990-1994	0.53 [0.23-1]	1 [0.27-1]	.0001
1995-1997	0.3 [0.22-0.45]	0.32 [0.23-0.54]	.1
ICU stay, d (median [25th-75th percentile])			
1990-1994	1.9 [1-2]	2 [1-3]	.0001
1995-1997	1.1 [0.9-1.9]	0.9 [0.9-1.9]	.06
Postoperative hospital stay, d (median, [25th-75th percentile])			
1990-1994	7 [6-9]	8 [7-10]	.0002
1995-1997	7 [6-9]	7 [6-9]	.4

LVEF, Left ventricular ejection fraction; *CCS,* Canadian Cardiovascular Society; *LITA,* left internal thoracic artery; *CPB,* cardiopulmonary bypass; *XCL,* aortic cross-clamp; *IABP,* intra-aortic balloon pump; *CCU,* coronary care unit; *OR,* operating room; *ICU,* intensive care unit.

operation (1982-1986, 1987-1991, or 1992-1997). Contingency table analysis was then used to examine changes in the prevalence of reoperative operations, risk factors, and hospital mortality and morbidity over time.

Results

Demographics

Prevalence of reoperative operation. Of 20,614 patients undergoing isolated coronary bypass operations at our institution between 1982 and 1997, 1230 (6.0%) were undergoing reoperative surgery. Both the absolute and relative prevalence of reoperative coronary operation rose from the early 1980s to a high in 1994 before reaching a plateau (Fig 1).

Additional risk factors in patients undergoing reoperative surgery. Demographic details of patients undergoing primary or reoperative procedures are listed in Table I. Patients undergoing reoperative surgery were more likely to be male, to have worse symptoms, to have greater LV dysfunction, and to require a more

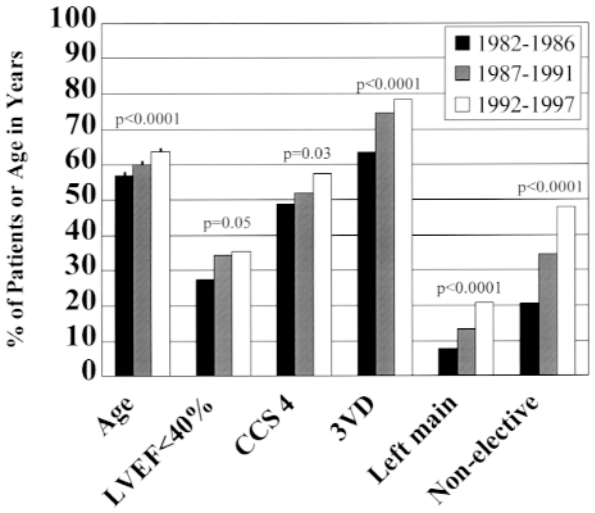

Fig 2. The increasing risk profile of patients undergoing a reoperative coronary procedure over 3 time periods (1982-1986, 1987-1991, and 1992-1997). Patient age, symptom class, extent of coronary artery disease, and the requirement for urgent or emergency operation all increased significantly with time. The prevalence of ventricular dysfunction and left main coronary artery stenosis were also significantly greater in later years. *3VD,* Triple vessel disease; *nonelective,* urgent or emergency operation.

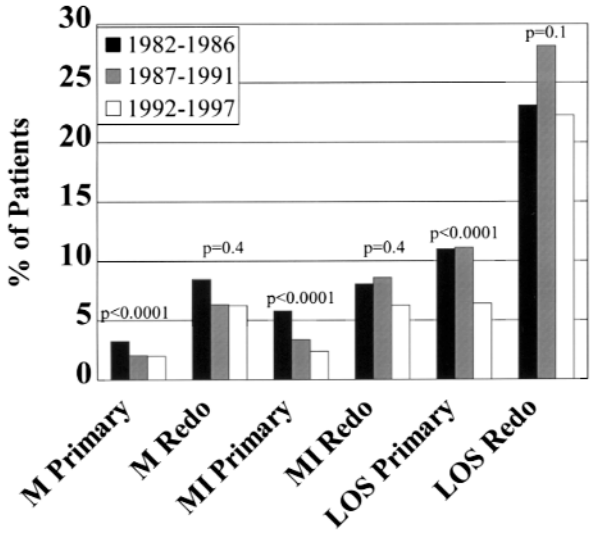

Fig 3. Trends in hospital outcomes, including hospital mortality *(M),* perioperative myocardial infarction *(MI),* and postoperative low-output syndrome *(LOS),* grouped by primary versus reoperative *(redo)* operation over 3 time periods (1982-1986, 1987-1991, and 1992-1997). Over the 16-year span of this study, hospital mortality, perioperative myocardial infarction, and postoperative low-output syndrome decreased significantly in patients undergoing first-time coronary bypass operations. In contrast, patients undergoing reoperative operations had lesser and nonstatistically significant improvements in survival and myocardial infarction and no definite reduction in the prevalence of low-output syndrome.

urgent operation than patients undergoing a primary operation. These patients were more likely to have had an intra-aortic balloon placed preoperatively either in the coronary care unit or in the operating room before the surgical procedure (Table I). Patient age, the extent of coronary disease, and the prevalence of left main coronary artery stenosis were, however, similar between groups.

Increasing risk profile of patients undergoing reoperation. In more recent years patients undergoing reoperation were older, more symptomatic, more likely to have triple vessel disease, and more likely to have left main coronary artery stenosis (Fig 2). The prevalence of LV dysfunction increased with time, as did the requirement for an urgent or emergency operation.

Intraoperative data. Intraoperative details, grouped by primary versus reoperative procedures, are listed in Table I. Patients undergoing reoperative procedures had fewer grafts placed than patients undergoing primary revascularization, despite slightly longer crossclamp times and substantially longer durations of cardiopulmonary bypass. Patients undergoing a primary operation had a left internal thoracic artery (LITA) graft used routinely. Patients undergoing reoperation were less likely to have a LITA graft, which may have been related to its use at the initial operation, lack of disease in the left anterior descending coronary artery (LAD), or the presence of a patent graft to the LAD.

From 1990-1997, cold cardioplegia was still used most commonly in patients undergoing a reoperative procedure (coronary perfusion, 0.8%; warm, 3.2%; tepid, 7.8%; cold, 88.2%). The cardioplegic solution was given continuously, rather than intermittently, in 31.3% of reoperations compared with 23.6% of primary procedures (P = .001). Retrograde cardioplegia or a combination of antegrade and retrograde cardioplegia was used in 38.8% of reoperations but only 17.9% of first-time bypass operations (P = .001).

In the early 1990s we abandoned the routine use of moderate systemic hypothermia during cardiopulmonary bypass, letting systemic temperatures drift to approximately 34°C. As a result, from 1990 to 1997, the lowest systemic temperature during cardiopulmonary bypass was 36°C to 37°C in 5.0%, 30°C to 35°C in 74.2%, 20°C to 29°C in 20.7%, and less than 20°C in 0.1% of reoperations.

Table II. *Multivariable predictors of hospital mortality in 1230 patients undergoing reoperative coronary bypass operations from 1982 through 1997*

Variable	*Regression coefficient*	*Odds ratio*	*95% CI*
Constant	–7.5 ± 1.2		
Age	0.037 ± 0.015	1.04	1.01–1.07
CCS	0.60 ± 0.23	1.8	1.2–2.8
Year of operation	–0.37 ± 0.15	0.69	0.52–0.93
LV grade	0.53 ± 0.14	1.7	1.3–2.2

The area under the ROC curve was 0.69. The Hosmer-Lemeshow goodness-of-fit *P* value was .39. *LV grade:* 1 = LVEF > 60%, 2 = LVEF 40%-60%, 3 = LVEF 20%-40%, 4 = LVEF < 20%. *Urgency:* 0 = Elective, 1 = same hospitalization, 2 = within 12 hours of a cardiac catheterization or cardiac event (eg, myocardial infarction and unstable angina). *Year of operation:* 1 = 1982-1986, 2 = 1987-1991, 3 = 1992-1997.

Table III. *Multivariable predictors of postoperative low-output syndrome in 1230 patients undergoing reoperative coronary bypass surgery from 1982 through 1997*

Variable	*Regression coefficient*	*Odds ratio*	*95% CI*
Constant	–4.4 ± 0.69		
Age	0.016 ± 0.0088	1.02	1.00–1.03
Female sex	0.62 ± 0.19	1.9	1.3–2.7
Year of operation	–0.24 ± 0.093	0.79	0.66–0.95
LV grade	0.46 ± 0.089	1.6	1.3–1.9
Urgency	0.20 ± 0.11	1.2	0.98–1.5
Left main stenosis	0.35 ± 0.19	1.4	0.98–2.0
Extent of CAD	0.32 ± 0.14	1.4	1.05–1.8

The area under the ROC curve was 0.64. The Hosmer-Lemeshow goodness-of-fit *P* value was .61. *LV grade:* 1 = LVEF >60%, 2 = LVEF 40%-60%, 3 = LVEF 20%-40%, 4 = LVEF <20%. *Urgency:* 0 = Elective, 1 = same hospitalization, 2 = within 12 hours of a cardiac catheterization or cardiac event (eg, myocardial infarction or unstable angina). *Year of operation:* 1 = 1982-1986, 2 = 1987-1991, 3 = 1992-1997. *Extent of CAD* = number of diseased vessels (1, 2, or 3).

Outcomes. Overall hospital mortality in patients undergoing reoperation was almost triple that of patients undergoing primary revascularization (Table I). The prevalence of myocardial infarction was doubled and that of postoperative low-output syndrome was tripled when patients were undergoing reoperation. Only 4.4% of patients undergoing first-time coronary bypass grafting required placement of an intra-aortic balloon pump postoperatively for hemodynamic support, either in the operating room or in the intensive care unit, but 16.1% of patients undergoing a reoperation required this mechanical assistance.

In the 742 patients undergoing reoperation from 1990 through 1997, hospital mortality was not significantly related to cardioplegic temperature (warm, 0%; tepid, 1.7%; cold, 6.57%; $P = .084$) or to continuity of administration, but the use of retrograde or combined antegrade and retrograde cardioplegia was associated with a mortality of 3.6% compared with 7.9% in patients receiving antegrade cardioplegia alone ($P = .013$). Mortality was also related to systemic perfusion temperatures (36°C-37°C, 2.7%; 30°C-35°C, 4.2%; 20°C-29°C, 12.4%; $P = .001$).

Trends in outcomes over time. Over the 16-year period of this study, hospital mortality and the prevalence of perioperative myocardial infarction and postoperative low-output syndrome decreased significantly in patients undergoing primary procedures (Fig 3) but not in the smaller number of patients undergoing reoperation. Hospital mortality was lower in patients undergoing reoperation after 1986, but this difference did not reach statistical significance.

In 1995 we switched to a "fast-track" perioperative management strategy, with consequent reductions in the duration of ventilation and intensive care unit and hospital stay.[2] From 1990 through 1994, the duration of ventilation and intensive care unit stay were both significantly greater in patients undergoing reoperative coronary procedures than in patients undergoing primary procedures (Table I). Hospital stay was not, however, different between these groups. From 1995 through 1997, with the advent of "fast-tracking," there were dramatic reductions in both groups in the duration of ventilation and intensive care unit stay. There was no significant reduction, however, in hospital length of stay in patients undergoing reoperation ($P = .7091$). Intensive care unit stay and hospital stay remained significantly greater in patients undergoing reoperation (Table I).

Predictors of hospital mortality and low-output syndrome

Independent predictors of hospital mortality. The independent predictors of mortality in all 1230 patients undergoing reoperative coronary surgery were increased age, greater CCS symptom class, earlier year of operation, and greater LV dysfunction (Table II). When this multivariable analysis was repeated, including only the 742 patients undergoing reoperation since 1990 in whom analysis of an expanded data set was possible, the independent predictors of mortality were greater CCS symptom class (odds ratio, 2.33; 95% confidence interval [CI], 1.16-4.67), greater LV grade (indicating greater LV dysfunction; odds ratio, 1.99; 95% CI, 1.31-3.01), peripheral vascular disease (odds

ratio, 2.43; 95% CI, 1.23-4.81), and failure to use retrograde cardioplegia (odds ratio, 2.74; 95% CI, 1.37-5.51; area under the ROC curve, 0.729; Hosmer-Lemeshow goodness-of-fit *P* value = .6691).

Independent predictors of low-output syndrome. Preoperative patient variables that were independently predictive of postoperative low cardiac output syndrome in all 1230 patients undergoing redo coronary revascularization were increased age, female sex, earlier year of operation, greater LV dysfunction, greater urgency of operation, left main coronary artery stenosis, and extent of coronary atherosclerosis (Table III). In the 742 patients reoperated on between 1990 and 1997, the independent predictors of postoperative low-output syndrome were female sex (odds ratio, 2.34; 95% CI, 1.47-3.73), greater LV grade (odds ratio, 1.70; 95% CI, 1.34-2.17), and diabetes (odds ratio, 2.13; 95% CI, 1.38-3.29; area under the ROC curve, 0.658; Hosmer-Lemeshow goodness-of-fit *P* value = .2170).

Discussion

Reoperative coronary bypass operations carry particular risks over and above those associated with primary procedures, including the risks associated with a second sternotomy and mediastinal dissection (potential injury to the right ventricle, innominate vein, aorta, and patent grafts), the greater extent of coronary atherosclerosis (associated with a lower number of grafts placed at reoperation and a higher prevalence of incomplete revascularization), and greater technical difficulty (increasing operative time and the durations of cardiopulmonary bypass and aortic crossclamping). Reoperation has been consistently identified as one of the most significant predictors of increased hospital mortality and morbidity.[1,2] However, cumulative advances in perioperative anesthetic management and myocardial protection have progressively reduced the risk of coronary artery bypass operations, including that of reoperative procedures.

We found that the prevalence of risk factors that have consistently predicted hospital mortality and morbidity in previous studies[1-3] increased significantly over the 16-year span of this study. These trends have paralleled those noted in patients undergoing primary procedures. In this series hospital mortality in patients undergoing redo bypass operations decreased from the 1982-1986 to the 1987-1991 cohorts. The prevalence of postoperative low-output syndrome increased, however, during this period, from approximately 23% to 28%, and the prevalence of myocardial infarction was unchanged, suggesting that as the patient risk profile increased, hospital morbidity also increased, despite the declining mortality. In the 1990s, as risk profiles increased further, both morbidity and mortality remained relatively constant, although low-output syndrome was slightly less common.

These findings coincided with a number of changes in our techniques of perioperative management and myocardial protection. In the mid-1980s, all surgeons at our institution adopted a single crossclamp technique and, in 1987-1988, a terminal "hot shot" of warm blood cardioplegia as a standard technique of myocardial protection.[4] In the early 1990s, we began a series of investigations of alternative techniques of cardioplegia that led to the use, in a subset of patients, of normothermic or tepid (29°C-30°C) cardioplegia.[5-7] However, because these changes were linked so closely to the year of operation, it was not possible to isolate the effects of these factors by multivariable analysis. Other factors, such as the routine excision of old vein grafts (except when a LITA graft was placed to a territory already served by a large but stenotic vein graft)[8] have remained more constant over time.

Analysis of patients undergoing reoperation since 1990, in whom an expanded data set included the technique of cardioplegia (antegrade, retrograde, or combined antegrade and retrograde), identified the use of antegrade cardioplegia alone as an independent predictor of mortality after reoperative surgery. Retrograde cardioplegia may permit more homogeneous delivery than antegrade cardioplegia to areas of myocardium supplied by occluded native coronary arteries or bypass grafts.[9,10] In territories perfused by pedicled arterial grafts, retrograde cardioplegia may be the only means to deliver cardioplegic solution effectively. In addition, retrograde cardioplegia may reduce the risk of atheromatous embolization from diseased vein grafts. Our data would certainly support the routine use of retrograde cardioplegia in patients undergoing reoperative revascularization.

In our current series no difference was observed between patients receiving retrograde cardioplegia alone and a combined technique of antegrade and retrograde cardioplegia. Gundry and colleagues[11] have reported excellent results (a 3% mortality) in 63 patients undergoing a combination of reoperative coronary, valvular, and aortic surgery, which they attribute to a "no-touch" technique of transatrial cannulation of the coronary sinus and the avoidance of antegrade cardioplegia.

Our recent (1992-1997) prevalence of mortality (6.3%) and myocardial infarction (6.3%) is consistent with other published reports. Stephan and colleagues[12] reported a mortality of 7.3% in 164 patients undergo-

ing elective coronary reoperation, with 6.1% of patients undergoing a Q-wave myocardial infarction. Akl and colleagues[13] reported an 8.3% prevalence of reoperation, with a 5.2% in-hospital mortality from Harefield Hospital. Fitzgibbon and associates[14] reported a mortality of 6.6% in 249 patients undergoing reoperation and thought that intraoperative graft atheroembolism was the major cause of morbidity and mortality.[14] Shimada and coworkers[15] reported outstanding results in a series of 200 reoperations, with a mortality of only 2.5% and a 0.5% prevalence of re-exploration for postoperative bleeding.[15]

The time interval between the first and second operation may affect the results of reoperation. Schmuziger and colleagues[16] noted a 9.2% mortality in 458 patients undergoing reoperation in Geneva. In their series mortality was 8.4% in patients requiring reoperation more than 1 year after the initial procedure but was 28% in those requiring reoperation in less than a year. In a series of 508 reoperations, Salomon and colleagues[17] reported an overall mortality of 6.9%, but mortality was lower (6.0%) in patients reoperated on within 10 years after the initial operation and higher (17.6%) in those operated on more than 10 years after their first operation. The necessity for reoperation within a year may be a marker of technical difficulties at the initial operation or extensive or rapidly progressive atherosclerosis, either of which would be expected to increase the risk of a subsequent operation. In addition, postoperative mediastinal adhesions are significantly more troublesome in this period. Conversely, reoperation more than 10 years after an initial procedure is likely related to advanced age, which we identified as a predictor of poor in-hospital outcomes.

Reoperative coronary surgery is now being carried out under increasingly risky conditions. Mortality has decreased and then stabilized, whereas perioperative morbidity has been relatively unchanged. Reducing the need for coronary reoperation may not be achievable by current standard therapies, but novel gene transfer strategies directed at inhibition of vein graft atherosclerosis and induction of native angiogenesis may offer the promise of one-time-only surgical revascularization.

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Discussion

Dr Scot Merrick *(San Francisco, Calif).* Dr Yau, you and your colleagues have provided us with a benchmark for reoperative coronary surgery. By nature, this is a descriptive report, and by the size of the study population and the time

interval, it gives us very important information. However, I still need more information to know what makes a redo operation high risk. For example, do you have data on how the type of coronary anatomy at the time of reoperation influences outcome? Is there a difference between patients with progression of native disease, graft disease, or prior incomplete revascularization?

Dr Yau. We have limited data on those variables in these 1230 patients. As you know, there may be a considerable overlap in the progression of native disease and graft atherosclerosis within territories in a given patient. We have looked at a subset of 473 of these patients in more detail to try to clarify the effects of the type of conduit and its patency and therefore indirectly some of the effects of graft disease on the outcomes of reoperation. We found that 52% of vein grafts to the anterior wall were occluded at reoperation, and in the majority of the patent vein grafts, there was significant disease. These figures contrasted with approximately 70% patency at the time of reoperation of arterial grafts to the anterior wall; therefore, there was obviously a significant effect not only of territory but also of the type of conduit used at the initial operation. Patency or occlusion of the original graft to the anterior wall did not have a significant effect on reoperative outcomes in these patients.

Incomplete revascularization is a factor that is unfortunately difficult to address in this kind of study. Those data were not gathered prospectively, and only the operating surgeon knows as he is leaving the operating room how complete or incomplete that revascularization was. There have been reports that early reoperation, which may be related either to incomplete revascularization or to technical difficulties at the time of the initial procedure, is associated with significantly increased risk. Schmuziger and colleagues reported that reoperations carried out more that a year after the initial operation carried an 8% mortality, whereas reoperations within the first year had a 28% mortality. These data, however, give us only peripheral evidence of that effect.

Dr Merrick. Thank you. I am inclined to believe that reoperating on patients with either progressive native disease that had been previously ungrafted or in patients who have had a previous incomplete revascularization may be a little bit safer.

Second, did you notice any effect on the time interval between the primary operation and the redo operation in terms of the long-term outcome?

Dr Yau. Unfortunately, we do not have complete data on the late outcomes of these patients other than their need for reoperation. We were not able to document any differences in outcomes related to the time between the initial operation and the second operation.

Dr Merrick. The fact that you did not observe any improvement in the incidence of reoperative myocardial infarction and low-output syndrome suggests that intraoperative management may be key. For example, at our Veterans Administration hospital several years ago, we presented a study showing that the incidence of myocardial ischemia during redo procedures was higher than that found in primary cases. With that, can you tell me how you deal with the old grafts? Do you excise them? Do you leave a graft to the LAD in place if you are planning on putting an ITA graft on that vessel? How would you deal with the previously stented vessel?

Dr Yau. We routinely excise all occluded and stenotic vein grafts. On occasion we will leave in a vein graft that looks absolutely pristine at reoperation and that is less than 5 years old. I think that we probably have a lower threshold for replacing an old vein graft to the LAD territory than we do to other areas. LAD vein grafts were more likely to be replaced by another vein graft than by an arterial graft because of concerns about potential hypoperfusion.

Regarding stented coronary arteries, I think that in patients with native coronary arteries that are now stented from top to bottom, a combination of angioplasty and repeat grafting may be useful. That is a problem that obviously is going to arise with greater frequency as time passes.

Dr Merrick. Thank you. I congratulate you on your mastery of the computer technology. You have shown us how we should be presenting information at future meetings.

Dr Yau. Thank you.

Dr J. Nilas Young *(Berkeley, Calif).* Dr Yau, I was interested to see that the results had somewhat plateaued in more recent years. Did you analyze the effect of cardiopulmonary bypass time relative to your results? It is somewhat of an old-fashioned analysis, but it may have some current relevance, given the opportunity to do some of these operations off pump.

Dr Yau. We did look at that in our initial analyses. Both cardiopulmonary bypass time and aortic crossclamp time have a significant relation to operative outcomes in these patients undergoing reoperation. We tend not to present those factors, however, because except for the case of off-pump surgery, it is not something that we can identify preoperatively or change intraoperatively or use to risk stratify these patients preoperatively. There have certainly been some very provocative data on early experience with off-pump coronary reoperations, but we have as yet limited experience with that.

Dr Steven Guyton *(Seattle, Wash).* You indicated that the risk factors had been increasing over time with the redo operations, and your results perhaps are not particularly better, but you did not indicate anything about the risk factors in the primary operations where we do see improving results. We seem to have seen increasing risk factors in both groups and yet have been getting results that are equal if not better in both groups. Do you have any information about risk factors in your primary operations?

Dr Yau. We have actually documented a similarly increasing risk profile of patients undergoing primary surgery. The results have, during that time, gradually improved despite increasing comorbidity and risk factors in the primary patients.